Effect of elevated ambient CO_2 concentration on water use efficiency of *Pinus sylvestriformis*[1]

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Abstract *Pinus sylvestriformis* is an important species as an indicator of global climate changes in Changbai Mountain, China. The water use efficiency (WUE) of this species (11-year old) was studied on response to elevated CO_2 concentration at 500±100 μL· L^{-1} by directly injecting CO_2 into the canopy under natural condition in 1998-1999. The results showed that the elevated CO_2 concentration reduced averagely stomatal opening, stomatal conductance and stomatal density to 78%, 80% and 87% respectively, as compared to normal ambient. The elevated CO_2 reduced the transpiration and enhances the water use efficiency (WUE) of plant.
Key words: *Pinus sylvestriformis*, Water Use Efficiency (WUE), Elevated CO_2 concentration

Introduction

Evidence from many studies shows that the concentration of atmospheric CO_2 is dramatically raising and a doubling of the present CO_2 concentration would occur during the last half of the next century. The rising of atmospheric CO_2 concentration is strongly correlated with the increase in global consumption of fossil fuels and also affected significantly by the clearing of forest (Bazzaz 1990).

Plants growing at various ambient concentration of CO_2 show great differences, including the processes of growth and physiology. Photosynthesis and transpiration are important processes of plant physiology. Many literatures have concluded that the processes of growth and physiology are directly affected by the atmospheric CO_2 enrichment. It is clear that elevated CO_2 slows transpiration rate and contributes to an increase in water use efficiency (WUE). Transpiration is reduced due to a lower stomatal conductance, and the stomatal conductance is dependent on the partial closure of guard cell that forms stomata on leaf surface. The elevated CO_2 can affect the morphology-interface characteristic of leaf (Han 1996).

Materials and methods

This research was conducted in Changbai Mountain (42° 24' N, 128° 06' E, at an altitude 738.1 m), in Northeast China. The study site, Changbai Mountain, belongs to temperate zone with an average annual air temperature 5 °C. Annual average precipitation is 719.3 mm. Annual average frost-free period is 116 d.

The research objective is 11 year-old *Pinus sylvestriformis*. Elevated CO_2 are simulated as follows: A 1-cm diameter PVC pipe, with an open top and enclosed end, was placed around the canopy in screwy form. The screwy distance was about 10 cm. The pipe was designed a lot of holes of various diameters toward the canopy. Mixed CO_2 and air was pressured into the pipe from the top and injected to the canopy. The CO_2 level of canopy is maintained at an approximate of 500±100 μL· L^{-1} and normal contrast was also made. Long-term CO_2 enrichment experiments have been continuously conducted in growing seasons of two years.

Results and discussions

Change of WUE and morphology

Table 1 showed the daily changes of stomata concerned with atmospheric CO_2 enrichment (500 μ·L^{-1} and normal concentration). The stomatal conductance and transpiration were measured directly by photosynthesis instrument. Stomatal opening and density were measured by scan electronic microscope (SEM).

It is clear that the elevated CO_2 concentration directly affects plant water relations. The increase of CO_2 concentration in the atmosphere around a leaf may cause the stomata to partially close so that transpiration rate or water loss are reduced from the leaf and the water use efficiency is raised.

Carbon dioxide enrichment has another important direct effect on morphology of leaf (i.e. interface characteristic). The Table 1 shows that when CO_2

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concentration is elevated to 500 μL• L^{-1} the average stomatal density, stomatal opening and stomatal conductance decreased to 87%, 78% and 80% respectively of that at the normal CO_2 concentration. The interface characteristic changed with elevated CO_2. This is as result of Morsion (1987) who analyzed that a doubling of CO_2 concentration to 660 μL•L^{-1} reduced stomatal conductance to 60% of that at 330 μL•L^{-1}.

Table 1. The measurements of stomata and transpiration at an elevated CO_2 concentration of 500±100 μL•L^{-1} *

CO_2 concentration /μL • L^{-1})	Time /h	Stomatal opening /$\times 10^{-12}$ • m^{-2}	Stomatal conductance /mmol • m^{-2} • s^{-1}	Stomatal density /$\times 10^{10}$ • m^{-2}	Transpiration rate /mmol • m^{-2} • s^{-1}
Normal	6:00	416.2	—	1.30	—
	10:00	482.9	200.1	1.42	4.36
	14:00	469.9	108.9	1.35	2.23
	20:30	4082.	138.3	0.95	0.45
500±100	6:00	333.2	—	1.20	—
	10:00	356.6	188.2	1.38	3.04
	14:00	340.7	100.3	1.05	2.02
	20.30	351.9	70.8	0.76	0.32

* The stomatal opening and density are the results of statistics data of SEM pictures, in which each data is an average of 15 pictures of 5 needles. The density is the number of stomata per unit of leaf area.

Plant biomass accumulation

Since elevated CO_2 affects interface characteristics, the substance exchange between leaf and atmosphere is influenced and biomass accumulation changes inevitably. Table 2 showed the change of biomass with rising of CO_2 concentration.

Table 2. The measurements of aboveground biomass of *Pinus sylvestriformis**

CO_2 Concentration /μL • L^{-1}	Height /cm	Apical shoots /cm	Whorl branches /cm
500	31.4	3.5	15.0
Normal	35.4	7.5	17.3

*The figures are attributed to plant growth in 2 years except the amounts of apical shoots.

Many reports revealed that the individual plant organs enlarge proportionally with added CO_2. When the CO_2 concentration increased, the leaf area becomes bigger (Rogers *et al.* 1994) and stem, branches and weight increased (Bazzaz 1990). However, some reports showed that elevated CO_2 concentration had negligible or negative effects on plant organs (Ceulemans *et al.* 1994; Rogers *et al.* 1994). In our study, with the only consideration of aboveground biomass, the *P. sylvestriformis* growing had negative relation with CO_2 rising. The elevated CO_2 concentration reduced growth in both height and branches.

Conclusions

The elevated atmospheric CO_2 affected the interface characteristic between the leaves and atmosphere. As results, the elevated CO_2 concentration reduced the stomatal opening, stomatal conductance and stomatal density of leaves and enhanced WUE of *P. sylvestriformis* in Changbai Mountain. Long-term experiments showed that the growth of apical shoots and whorl branches were slowed down.

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